Final Technical Report

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Center Name: Southern California Particle Center and Supersite (SCPCS)
Center Director: John R. Froines
Title: Ultrafine Particles and Freeways
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EPA Project Officer: Stacey Katz/Gail Robarge
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RFA: Airborne Particulate Matter (PM) Centers (1999)
Research Category: Particulate Matter

Topic B: Studies of Emission Sources and Related Adverse Health Effects

Objective(s) of the Research Project:

Background

It is now well established that increases in the concentration of fine particles (F) in urban areas are associated with increases in morbidity and mortality. It is not known what properties of F cause these effects, but one candidate is ultrafine particles (UF). These are particles less than 100 nm or 0.1 µm in size and are found near combustion sources, such as motor vehicles. In an urban environment motor vehicle emissions usually constitute the most significant source of UF. However, there is very little information available either as to the size of the particles or the number concentration of UF emitted by vehicles in urban areas.

This research focuses on characterizing UF as they are transported away from a major emission source—a freeway. The overall objective of this research is to systematically evaluate and quantitatively predict UF particle concentration in the vicinity of freeways, particularly as they are transported downwind from freeways and into residences near freeways. Results from this study provide data and tools that allow epidemiologists and toxicologists to estimate exposure to UF in the vicinity of major highways.

Summary of Findings:

Particle Instrumentation Unit (PIU)

In collaboration with Dr. Constantinos Sioutas (University of Southern California [USC]), we designed, fabricated, and implemented a state-of-the-art movable Particle Instrumentation Unit (PIU) for research monitoring of the full size range of particulate air pollution at different locations in Southern California. The PIU is a movable laboratory designed to provide detailed characterization of the chemical and physical properties of ambient particulate matter, using state-of-the-art instrumentation, to support the Southern California Particle Center and Supersite (SCPCS). The PIU is housed in a 20-foot long trailer, which was modified at University of California-Los Angeles (UCLA) and placed into service in fall 2000. It has been in full operation at six locations in the Los Angeles Basin (LAB), Claremont, Downey, Riverside, Rubidoux, and USC for at least 3 months at each site. The PIU continuously measures the ambient particle size distribution over the particle size range of 10 nm to 20 µm as well as mass concentration and meteorological data, specifically, temperature, humidity, wind speed, and wind direction. Weekly particle size-segregated samples are taken with MOUDI cascade impactors for detailed chemical analysis. CO, ozone and NO_x are monitored routinely.

Meteorological Tower

The lower part of the 10 m tower for the meteorological instruments consists of two 3-meter tower sections and the upper part is a 2-inch OD aluminum pole with a 1.25-foot fiberglass pole extension. The pole section is removable for transportation. With the base plate the tower weighs approximately 50 kg (110 lbs).

The tower is hinged at its attachment point at the top front of the trailer. The tower is well balanced and is easy and safe to lower and raise. It can be lowered or raised by one person for transportation in about 30 minutes. It can be partially lowered for calibration in 5–10 minutes.

Inlets

All sampling inlets that do not use a PM_{10} inlet were modified to use 180° stainless steel sweep elbows. This is to prevent rain from getting into the trailer or the sampling systems and instruments.

Pump Enclosures

Three noise reduction enclosures for sampling pumps were constructed and tested. Each unit consists of a lockable plywood box, 0.56 X 0.81 X 0.37 m high, on casters. Each unit can accommodate two large Gast vane pumps or three medium sized ones. The boxes are ventilated with an electric fan and all outlet air is HEPA filtered. The pumps can be turned on independently. A relay turns the cooling fan on if either pump is turned on. Semi-rigid fiberglass board lines part of the box for sound absorption. The enclosure reduces noise levels by 17.5 dBA.

Ultrafine Particles Near Freeways

To obtain data to model the concentration and size distribution of UF in the vicinity of freeways, we made detailed measurements in summer and winter of UF near the 405 and 710 freeways, two of the busiest in the country. Interstate 405 has more than 95% gasoline vehicles and Interstate 710 has up to 30% heavy-duty diesel vehicles; and thus these two roads represent the range of vehicle mix one is likely to encounter in urban areas.

Particle number concentration and size distribution in the size range from 7 nm to 220 nm were measured by a condensation particle counter (CPC) and a scanning mobility particle spectrometer (SMPS), respectively. Measurements were taken at 30 m, 60 m, 90 m, 150 m, and 300 m downwind and 300 m upwind from Interstate highway 405 at the VA National Cemetery and at similar positions near Interstate 710. At each sampling point, the concentration of carbon monoxide, black carbon and particle mass were also measured by a Dasibi CO monitor, an Aethalometer and a DataRam, respectively. Simultaneous measurements were made of wind speed and direction. Traffic volume was estimated by manually counting vehicles during replay of video recordings.

<u>Results</u>

A detailed description of the project's results can be found in Zhu, et al., 2002a; Zhu, et al., 2002b; and Zhu, et al., 2004. As shown in Figure 1, for the conditions of these measurements, the relative concentrations of CO, black carbon and particle number track each other well as one moves away from the freeway. Particle number concentration (6–220 nm) decreased exponentially with downwind distance from the freeway.

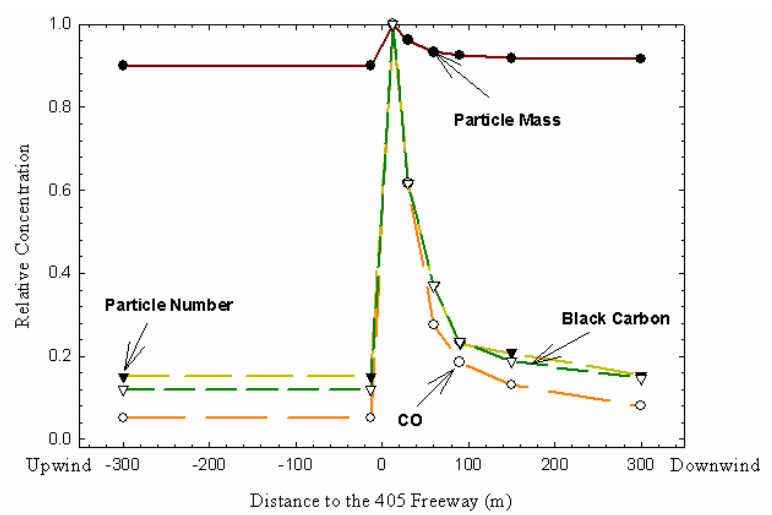


Figure 1. Relative Mass, Number, Black Carbon, CO Concentration Near the 405 Freeway

For the 405 freeway the average concentrations of CO, black carbon, particle number and PM mass at 30 m were in the range of 1.7 to 2.2 ppm, 3.4 to 10.0 μg/m^3, 1.3×10^5 to 2.0×10^5 /cm^3 and 30.2 to 64.6 μg/m^3, respectively. The total particle number concentration decreased exponentially with down wind distance from the freeway. The average traffic flow during the sampling period was 13,900 vehicles/hr. 93% of vehicles were gasoline powered cars or light trucks. The measured number concentration tracked traffic flow well. Thirty meters downwind from the freeway, three distinct modes were observed with geometric mean diameters of 12.6 nm, 27.3 nm and 65.3 nm, respectively. The smallest mode, with a peak concentration of 1.6×10^5 /cm^3, disappeared at distances greater than 90m from the freeway. Ultrafine particle concentration measured at 300 m downwind of the freeway was indistinguishable from upwind background concentration.

Atmospheric dispersion, coagulation, condensation and evaporation appear to contribute to the rapid decrease in particle number concentration and change in particle size distribution with increasing distance from the freeway. The maximum number concentration that was observed near the freeway was about 25 times greater than that for upwind locations. It suggests that people, who live, work, or travel on or within 100 m downwind of major traffic sources, will have much higher UF particle exposure than those who live farther away from such sources. The decay rates of CO and black carbon (BC) are slightly greater in summer than in winter for both freeways suggesting a weaker atmospheric dilution effect in winter. Particle number concentration in the size range of 6–12 nm is significantly higher in winter than in summer. The associated concentration in that size range decreased at a slower rate in winter than in summer. These results suggest that wintertime conditions favor greater UF particle formation, possibly due to increased condensation of organic vapors and slower atmospheric dilution.

A mathematical model was developed to predict UF particle number concentrations near freeways. Particle number based emission factors were estimated based on vertical measurement. Model inputs are traffic, wind, and location. Within the range of our data, the model predicts particle number concentration near freeways with more than 90% accuracy. Atmospheric dispersion was found to be the dominant mechanism in determining the particle number concentration near freeways. With appropriate particle emission factors, traffic compositions, and meteorological data, particle number concentrations near freeways can be quantitatively estimated by this model (Zhu and Hinds, 2005). These data may be useful for epidemiological studies to estimate exposure to UF in the vicinity of major highways and to evaluate their adverse health effects. In collaboration with researchers from UC-Davis, the dynamic changes of UF particle size distribution downwind of the freeways were also studied (Zhang, et al., 2004), and size-segregated emission factors were determined (Zhang, et al., 2005).

Similar measurements were repeated at night near the 405 freeway to study the diurnal pattern of UF near freeways. Average traffic flow at night was about 25% of that observed during the day. Particle number concentration measured at 30 m downwind from the freeway was 80% of earlier daytime measurements. This discrepancy between changes in traffic counts and particle number concentrations is apparently due to the decreased temperature, increased relative humidity, and lower wind speed at night. Particle size distributions do not change as dramatically as they did during the daytime. Particle number concentration decays exponentially downwind from the freeway similar to what was observed during the day, but at a slower rate. No particle number concentration gradient has been observed for the upwind side of the freeway. No $PM_{2.5}$ and very weak PM_{10} concentration gradients were observed downwind of the freeway at night. Ultrafine particle number concentration measured at 300 m downwind from the freeway was still distinguishably higher than upwind background concentration at night. Temperature and relative humidity affect UF particle formation significantly especially for the primary mode around 20 nm (Zhu, et al., 2006b).

Indoor and Outdoor (I/O) Relationships for Ultrafine Particles

Many urban residences, schools, and businesses are located in close proximity to high-density roadways. Consequently, indoor environments in urban areas may experience significant concentrations of outdoor UF. Given that people spend over 80% of their time indoors, understanding transport of UF from outdoor to indoor environments is important for assessing impacts of outdoor particulate matter on human health.

Indoor particle concentration is governed by indoor and outdoor sources, exchange rates, and particle physico-chemical characteristics. Indoor particle concentrations, therefore, depend on the dynamics of the transport and fate of outdoor particles in the indoor environments. Previous research in this area has focused on $PM_{2.5}$ and PM_{10} properties and behavior (Jones, et al., 2000; Thatcher and Layton, 1995). These studies found outdoor particles to be present at significant concentration in indoor spaces. In addition, the building shell was found to be ineffective in removing infiltrating particles. Considering health implications of UF particle exposure, it is important to assess particles' penetration characteristics into indoor environments and the relationship between their physical and chemical properties and infiltration. The overall objective of this project is to improve our knowledge of the indoor levels of UF from outdoor origin, especially those from motor vehicles in the vicinity of freeways.

Four two-bedroom apartments near the 405 Freeway in Los Angeles, CA were recruited for this study. Three of the four apartments (Apt 1, 2 and 3) are on the eastern side of the 405 Freeway. These three apartments are on the third floor with windows 3 m above a sound barrier wall next to the freeway. The horizontal distances between apartments 1–3 and the wall range from 15 m to 40 m. All three apartments are separated by no more than 50 m. The fourth apartment (Apt 4) is on the opposite, western, side of the 405 Freeway, 15 m from the sound barrier wall. Apt 4 is on the second floor with windows 0.5 m above the wall. All the apartments are about 8 years old with central mechanical ventilation systems that can be turned off. Dominant wind direction during the day is from west to east (sea breeze) and at night times winds are light with a slight east to west flow.

Indoor and outdoor UF particle size distributions (6 nm to 220 nm) were measured concurrently under different ventilation conditions without indoor sources or aerosol generation activities. Figure 2 shows averaged particle size distributions and indoor/outdoor ratios for apartment 1. Figure 2a shows day time (10 am–5 pm) and Figure 2b shows night time indoor and outdoor particle size distributions. Figure 2c shows particle size dependent indoor/outdoor ratios during day and night times.

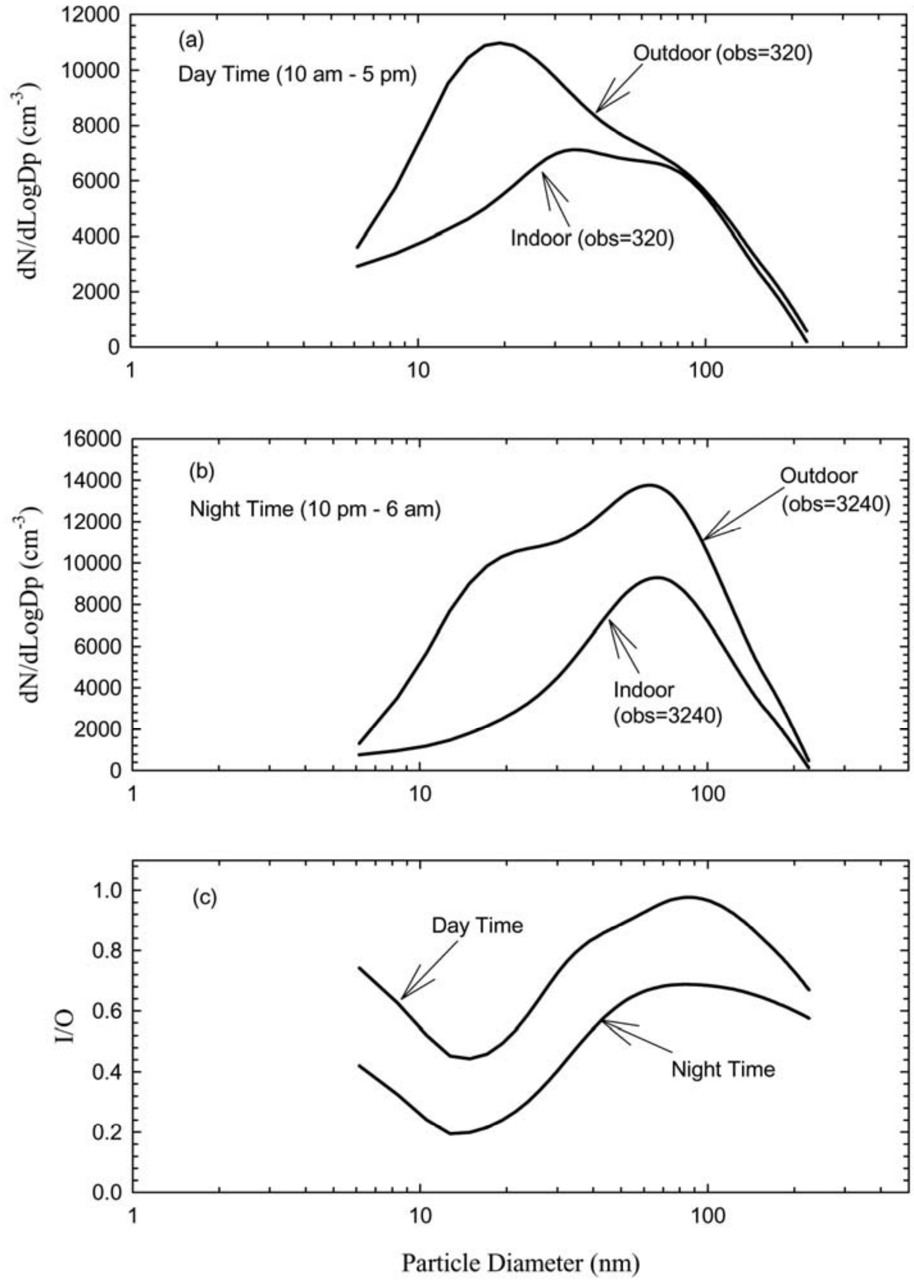
Figure 2(a) shows a daytime outdoor particle size mode near 20 nm, consistent with previous reports (Zhu, et al., 2002b). No such mode exists for indoor observations, and indoor particle number concentration is much more stable than outdoors. Night time particle number concentrations, shown in Figure 2(b), are comparable to their day time values. Although traffic densities are lower during the night, vehicle speeds on the freeway are much faster. It has been shown previously that faster vehicles generate more particles (Zhu, et al., 2002b). Lower nighttime temperatures, may also result in higher emission factors for particle number, as described by Kittelson (1998) and observed in the nighttime study (Zhu, et al., 2006b). Another reason for higher particle number concentrations during the night may be lower wind speeds, and a lower atmospheric mixing height, thus weaker atmospheric dilution effects.

As Figure 2(c) shows, I/O ratios during day and night times exhibit similar trends and shapes. Day and night I/O profiles for particles above 20 nm are consistent with theoretical curve shapes. Curves for particles below 20 nm do not correspond to the accepted theory, as no downward trend is observed for both day and night time observations. One possible reason is the low instrument detection limit in that size range, and thus large variability and less statistical confidence in data on particles below 20 nm. Another possible reason may be the unique, semi-volatile, nature of freeway UF. Freshly emitted freeway UF are known to have a considerable fraction of volatile components, especially particles below 50 nm (Kittelson, 1998). For example, some of the particles in the 20–40 nm size range may lose their volatile components and become particles of 20 nm or less. Such loss of volatile components has been observed previously (Lunden, et al., 2003). The volatility properties of freeway UF were reported in a companion paper to this study (Kuhn, et al., 2005). The difference between day and night I/O may be due to higher air exchange rates during daytime.

<u>Pilot Study of I/O Relationships for Vehicles</u>

Very limited information is available on human exposure to freshly emitted UF while commuting on major roads and freeways. We conducted experiments to measure in-cabin and outdoor particle number concentration and size-distributions while driving three vehicles on Los Angeles freeways. Particle number concentrations and size distributions were measured under different operating conditions of vehicle ventilation system (windows open, AC on/off, recirculation on/off). Outside changes in particle counts caused corresponding in-cabin changes approximately 30–40 s later, indicating an air exchange rate of about 100 hr^{-1} when the fan and air conditioning were set to on. Maximum in-cabin protection (~85%) was obtained with ventilation conditions of "recirculation on" and high fan speeds. In-cabin and outdoor particle size distributions in the 7–300 nm range were observed to be mostly bimodal, with the primary peak occurring at 10–30 nm and the secondary peak occurring at 60–100 nm. The factory-installed particle filter in the vehicle ventilation system offered an in-cabin protection of about 50% for particles in the 7–40 nm size range, and 20–30% for particles in the 40 to ~200 nm size range. Based on these results, a manuscript has been submitted for publication (Zhu, et al., 2006a).

Figure 2. Averaged (a) Day Time, (b) Night Time Outdoor and Indoor Particle Size Distributions and (c) Size Dependant I/O Ratios in Apt 1.



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